CLAIMS

We claim:

1. A method comprising:

characterizing quantization noise in reconstructed data generated in response to application of an inverse wavelet transform; and

removing the quantization noise from the reconstructed data constructed during decoding.

2. The method defined in Claim 1 wherein removing the quantization noise comprises performing wavelet denoising using an enhancement wavelet transform.

3. The method defined in Claim 2 wherein the enhancement wavelet transform is a different transform than the inverse wavelet transform.

4. The method defined in Claim 2 wherein the enhancement wavelet transform is the same transform than the inverse wavelet transform.

5. The method defined in Claim 2 wherein performing wavelet denoising comprises applying the enhancement wavelet transform on a subset of all decomposition levels to which the inverse transform is to be applied.

6. The method defined in Claim 5 wherein the subset of decomposition levels comprise a set of consecutive decomposition levels.

7. The method defined in Claim 5 wherein the subset of decomposition levels comprise a set of non-consecutive decomposition levels.

8. The method defined in Claim 1 wherein the inverse wavelet transform is part of a JPEG 2000 decoder and is applied as part of using the decoder on a JPEG 2000 codestream.

9. The method defined in Claim 2 wherein performing wavelet denoising comprises controlling denoising using level 2 enhancement wavelet transform coefficients.

10. The method defined in Claim 9 wherein controlling denoising comprises setting all level 1 enhancement wavelet transform coefficients to zero where a corresponding level 2 coefficient is zero or has a different sign.

11. The method defined in Claim 1 wherein the quantization noise depends on quantization performed and the inverse wavelet transform applied.

12. The method defined in Claim 1 further comprising:

decoding image data, including applying the inverse wavelet transform to compression wavelet transform coefficients at level L to generate samples at enhancement wavelet transform level L-1 having quantization noise.

13. The method defined in Claim 12 further comprising repeatingly applying the inverse wavelet transform and removing quantization noise after each application of the inverse wavelet transform.

14. The method defined in Claim 1 further comprising performing a deblurring operation on the reconstructed samples to enhance sharpness of an image.

15. The method defined in Claim 1 wherein removing the quantization noise comprises:

applying an M-level forward transform to LL components;

thresholding coefficients; and

applying a M-level inverse transform to thresholded coefficients to create denoised LL components.

16. The method defined in Claim 15 wherein thresholding coefficients comprises determining a threshold based on a scalar quantizer Q, where Q is a rational number.

17. The method defined in Claim 17 wherein the threshold is $\frac{1}{\sqrt{2}}Q$.

18. The method defined in Claim 17 wherein the inverse wavelet transform is a one dimensional, 5,3 wavelet transform.

19. The method defined in Claim 16 wherein the threshold is $1.5Q$.

20. The method defined in Claim 19 wherein the inverse wavelet transform is a two dimensional, 5,3 wavelet transform.

21. The method defined in Claim 16 wherein the inverse wavelet transform is a Daubechies 9,7 filter.

22. The method defined in Claim 16 wherein scalar quantizer Q is equal to $2^{M_b-(P+C-\chi)} \cdot \Delta_b$ where

M_b is $G+\varepsilon_b-1$ where G is a number of guard bits and ε_b is an exponent indicated in a first tag in a codestream,

$(P + C - \chi)$ is the number of bitplanes decoded, and

Δ_b is indicated in a second tag in the codestream.

23. The method defined in Claim 16 wherein the scalar quantizer Q is determined from headers in a JPEG 2000 codestream.

24. The method defined in Claim 15 wherein at least two thresholds are used for different regions of samples.

25. The method defined in Claim 24 wherein different regions of samples correspond to different codeblocks of wavelet coefficients.

26. The method defined in Claim 24 wherein different samples have different last coding passes.

27. The method defined in Claim 15 wherein M equals 1.

28. The method defined in Claim 15 wherein the forward and inverse transforms are forward and inverse Harr transforms.

29. The method defined in Claim 15 further comprising rescaling of coefficients after thresholding the coefficients.

30. The method defined in Claim 29 wherein rescaling components comprises multiplying non-zero coefficients at level m by $R^{1/l} \cdot 2^{m\alpha}$, where m equals 1...M, where α is the parameter that determines the degree of smoothing or sharpening and R is the renormalization constant that preserves the norm of an image.

31. The method defined in Claim 15 wherein thresholding of coefficients comprises setting a wavelet coefficient to zero if the absolute value of the wavelet coefficient is less than a threshold and not changing the wavelet coefficient if its absolute value is greater than or equal to the threshold.

32. The method defined in Claim 15 wherein thresholding of coefficients comprises shrinking a value of wavelet coefficient toward zero

by an amount of a threshold if the absolute value of the wavelet coefficient is greater than or equal to the threshold.

33. The method defined in Claim 13 wherein the threshold comprises an average of thresholds corresponding to the maximal approximation error of four neighboring samples.

34. The method defined in Claim 13 wherein the threshold comprises a maximum of thresholds corresponding to the maximal approximation error of four neighboring samples.

35. The method defined in Claim 1 wherein characterizing quantization noise comprises computing differences between neighboring samples.

36. The method defined in Claim 1 wherein the quantization noise is not uniformally distributed throughout the reconstructed data.

37. The method defined in Claim 1 wherein the quantization noise is not continuous throughout the reconstructed data.

38. The method defined in Claim 1 wherein the quantization noise has discrete values.

39. The method defined in Claim 1 wherein the quantization noise has rational values.

40. The method defined in Claim 39 wherein the inverse wavelet transform is applied using a rational wavelet filter.

41. The method defined in Claim 1 wherein characterizing quantization noise comprises characterizing scalar quantization of wavelet coefficients.

42. The method defined in Claim 1 wherein the quantization noise is scalar quantization noise.

43. A decoder comprising:

an inverse wavelet filter unit to apply an inverse wavelet transform;

a quantization noise characterization unit to characterize quantization noise in reconstructed data generated in response to application of the inverse wavelet transform; and

a quantization noise removal unit to remove the quantization noise from the reconstructed data constructed during decoding.

44. The decoder defined in Claim 43 wherein the quantization noise removal block comprises a denoising unit to perform wavelet denoising using an enhancement wavelet transform.

45. The decoder defined in Claim 44 wherein the enhancement wavelet transform is a different transform than the inverse wavelet transform.

46. The decoder defined in Claim 44 wherein the enhancement wavelet transform is the same transform than the inverse wavelet transform.

47 The decoder defined in Claim 44 wherein performing wavelet denoising comprises applying the enhancement wavelet transform on a subset of all decomposition levels to which the inverse transform is to be applied.

48. The decoder defined in Claim 47 wherein the subset of decomposition levels comprise a set of consecutive decomposition levels.

49. The decoder defined in Claim 47 wherein the subset of decomposition levels comprise a set of non-consecutive decomposition levels.

50. The method defined in Claim 44 wherein the inverse wavelet transform is part of a JPEG 2000 decoder and is applied as part of using the decoder on a JPEG 2000 codestream.

51. The decoder defined in Claim 43 wherein the quantization noise depends on quantization performed and the inverse wavelet transform applied.

52. The decoder defined in Claim 43 wherein the inverse wavelet filter unit applies the inverse wavelet transform to compression wavelet coefficients at level L to generate samples at the enhancement wavelet transform level L-1 having quantization noise.

53. The decoder defined in Claim 51 wherein the inverse transform unit repeatedly applies the inverse wavelet transform and the quantization noise removal unit removes quantization noise after each application of the inverse wavelet transform.

54. The decode defined in Claim 44 wherein the denoising unit performs a deblurring operation on reconstructed samples to enhance sharpness of an image.

55. The decoder defined in Claim 43 wherein the quantization noise removal block removes quantization noise by

applying an M-level forward transform to LL components;

thresholding coefficients; and

applying a M-level inverse transform to thresholded coefficients to create denoised LL components.

56. The decoder defined in Claim 55 wherein the quantization noise removal unit performs thresholding of coefficients by determining a threshold based on a scalar quantizer Q, where Q is a rational number.

57. The decoder defined in Claim 55 wherein the quantization noise removal unit rescales coefficients after thresholding the coefficients.

58. The decoder defined in Claim 57 wherein the quantization noise removal unit rescales components by multiplying non-zero coefficients at level m by $R^{1/l} \cdot 2^{m\alpha}$, where m equals 1...M, where α is the parameter that determines the degree of smoothing or sharpening and R is the renormalization constant that preserves the norm of an image.

59. The decoder defined in Claim 55 wherein the quantization noise removal unit thresholds coefficients by setting a wavelet coefficient to zero if the absolute value of the wavelet coefficient is less than a threshold

and not changing the wavelet coefficient if its absolute value is greater than or equal to the threshold.

60. The decoder defined in Claim 55 wherein the quantization noise removal unit thresholds coefficients by shrinking a value of wavelet coefficient toward zero by an amount of a threshold if the absolute value of the wavelet coefficient is greater than or equal to the threshold.

61. The decoder defined in 55 wherein thresholding is performed using a threshold, and further wherein the threshold comprises an average of thresholds corresponding to the maximal approximation error of four neighboring samples.

62. The decoder defined in Claim 55 wherein thresholding is performed using a threshold, and further wherein the threshold comprises a maximum of thresholds corresponding to the maximal approximation error of four neighboring samples.

63. An article of manufacture comprising one or more recordable media with executable instructions stored thereon which, when executed by a system, cause the system to:

characterize quantization noise in reconstructed data generated in response to application of an inverse wavelet transform; and

remove the quantization noise from the reconstructed data constructed during decoding.

64. The article of manufacture defined in Claim 63 further comprising instructions which, when executed by the system, cause the system to remove the quantization noise comprises performing wavelet denoising using an enhancement wavelet transform.

65. The article of manufacture defined in Claim 63 wherein the enhancement wavelet transform is a different transform than the inverse wavelet transform.

66. The article of manufacture defined in Claim 65 wherein the enhancement wavelet transform is the same transform than the inverse wavelet transform.

67 The article of manufacture defined in Claim 65 wherein the instructions to perform wavelet denoising comprises instructions to apply the enhancement wavelet transform on a subset of all decomposition levels to which the inverse transform is to be applied.

68. The article of manufacture defined in Claim 67 wherein the subset of decomposition levels comprise a set of consecutive decomposition levels.

69. The article of manufacture defined in Claim 67 wherein the subset of decomposition levels comprise a set of non-consecutive decomposition levels.

70. The article of manufacture defined in Claim 63 wherein the inverse wavelet transform is part of a JPEG 2000 decoder and is applied as part of using the decoder on a JPEG 2000 codestream.

71. The article of manufacture defined in Claim 63 wherein the quantization noise depends on quantization performed and the inverse wavelet transform applied.

72. The article of manufacture defined in Claim 63 further comprising instructions which, when executed by the system, cause the system to:

decode image data, including applying the inverse wavelet transform to compression wavelet transform coefficients at level L to generate samples at enhancement wavelet transform level L-1 having quantization noise.

73. The article of manufacture defined in Claim 63 further comprising instructions which, when executed by the system, cause the system to repeatedly apply the inverse wavelet transform and remove quantization noise after each application of the inverse wavelet transform.

74. The article of manufacture defined in Claim 63 further comprising instructions which, when executed by the system, cause the system to perform a deblurring operation on the reconstructed samples to enhance sharpness of an image.

75. The article of manufacture defined in Claim 63 wherein the instructions to remove the quantization noise comprise instructions to:

apply an M-level forward transform to LL components;

threshold coefficients; and

apply a M-level inverse transform to thresholded coefficients to create denoised LL components.

76. A method comprising:

applying an inverse discrete wavelet transform to LL coefficients and high pass coefficients at level L to generate samples at level L-1 having quantization noise;

removing the quantization noise in reconstructed LL components computed during the inverse wavelet transform, wherein the quantization

noise depends on quantization performed and the inverse wavelet transform applied.

77. An encoder comprising:

a wavelet enhancement unit to perform denoising and deblurring on an image using an enhancement wavelet transform; and

a compressor coupled to the wavelet enhancement unit to compress enhanced image output from the wavelet enhancement unit using a compression wavelet transform.

78. The encoder defined in Claim 77 wherein an amount of smoothing and an amount of quantization are chosen together.

79. The encoder defined in Claim 77 further comprising a rate control unit coupled to monitor a compressed file output from the compressor and coupled to the wavelet enhancement unit to signal the wavelet enhancement unit to increase or decrease an amount of smoothing if the bit-rate as indicated by examining the compressed file is higher or lower, respectively, than a predetermined target rate.

80. The encoder defined in Claim 77 wherein the compressor performs JPEG 2000 compression.

81. The encoder defined in Claim 77 wherein the wavelet enhancement unit performs denoising at level m, where m is greater than or equal to 1.

82. The encoder defined in Claim 77 wherein the wavelet enhancement unit performs denoising at levels 1 . . m-1, using level m.

83. The encoder defined in Claim 82 wherein the wavelet enhancement unit sets coefficients at levels 1 . . m-1 to 0, if a corresponding coefficient at level m is 0.

84. The encoder defined in Claim 82 wherein the wavelet enhancement unit sets each coefficient at levels 1 . . m-1 to 0, if a corresponding coefficient at level m is 0 or has a different sign.

85. A method comprising:

performing denoising and deblurring on an image using an enhancement wavelet transform; and

compressing enhanced image output using a compression wavelet transform.

86. The method defined in Claim 85 wherein an amount of smoothing and an amount of quantization are chosen together.

87. The method defined in Claim 85 further comprising monitoring a compressed file output from the compressor and signalling a wavelet enhancement unit to increase or decrease an amount of smoothing if the bit-rate as indicated by examining the compressed file is higher or lower, respectively, than a predetermined target rate.

88. The method defined in Claim 85 further comprising performing denoising at level m, where m is greater than or equal to 1.

89. The method defined in Claim 85 further comprising performing denoising at levels 1 . . m-1, using level m.

90. The method defined in Claim 89 further comprising setting coefficients at levels 1 . . m-1 to 0, if a corresponding coefficient at level m is 0.

91. The method defined in Claim 89 further comprising setting each coefficient at levels 1 . . m-1 to 0, if a corresponding coefficient at level m is 0 or has a different sign.

92. The method of Claim 85 further comprising performing denoising;

performing sharpening and smoothing to enhance edges and reduce possible quantization noise effect; and

compressing the image into a compressed file using threshold information.

93. An article of manufacture comprising one or more recordable media with executable instructions stored thereon which, when executed by a system, cause the system to:

perform denoising and deblurring on an image using an enhancement wavelet transform; and

compress enhanced image output from the wavelet enhancement unit using a compression wavelet transform.

94. An apparatus comprising:

a denoising unit;

a forward wavelet sharpening and smoothing unit to enhance edges and reduce possible quantization noise effects in response to an image; and

a compressor coupled to the image to compress the image into a compressed file using threshold information.

95. The apparatus defined in Claim 94 wherein the threshold information comprises thresholds for each subband.

96. The apparatus defined in Claim 94 wherein the threshold information comprises thresholds used as a quantization parameter.

97. The apparatus defined in Claim 94 wherein the compressor comprises a JPEG 2000 compressor.

98. The apparatus defined in Claim 94 wherein the wavelet sharpening and smoothing unit generates different thresholds for different coefficients within a subband and the compressor compresses data by, in part, applying quantization on each codeblock based on the different thresholds.

99. The apparatus defined in Claim 94 wherein the wavelet sharpening and smoothing unit provides different thresholds for regions smaller than a codeblock and combines thresholds to produce one threshold for the codeblock.

100. The apparatus defined in Claim 99 wherein the wavelet sharpening and smoothing unit combines the thresholds for regions smaller

than a codeblock to produce one threshold for the codeblock using averaging.

101. The apparatus defined in Claim 99 wherein the wavelet sharpening and smoothing unit combines the thresholds for regions smaller than a codeblock to produce one threshold for the codeblock using a minimum threshold determination for the whole block.

102. The apparatus defined in Claim 99 wherein the wavelet sharpening and smoothing unit combines the thresholds for regions smaller than a codeblock to produce one threshold for the codeblock using a maximum threshold determination for the whole block.

103. The apparatus defined in Claim 99 wherein the wavelet sharpening and smoothing unit combines the thresholds for regions smaller than a codeblock to produce one threshold for the codeblock using a value in between maximum and minimum thresholds for the codeblock/region.